

November 18, 2003

Dr. Harin Ullal, MS3212
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National Renewable Energy Laboratory
1617 Cole Blvd
Golden, CO 80401

Re: Twenty-Third Monthly Report #NDJ-2-30630-11

Dear Harin,

This letter comprises the monthly technical status report for ITN's subcontract # NDJ-2-30630-11, "Plasma-Assisted Coevaporation of S and Se for Wide Band Gap Chalcopyrite Photovoltaics", under the Thin Film Partnership Program. The reported work was performed during the eleventh month of phase 2 for this contract (twenty-third month overall), which is October 7, 2003 through November 7, 2003. This report describes activities performed by ITN, as well as those performed by lower-tier subcontractor Colorado School of Mines (CSM), under the direction of Dr. Colin Wolden.

1. Program Goals and Approach

Our primary objective under this program is to determine if the chalcogen in CIGS co-evaporation can be delivered more effectively by activation with a plasma. Possible advantages of plasma-assisted co-evaporation (PACE) are

- increased utilization of chalcogens,
- decreased deposition temperatures,
- decreased deposition times, and
- increased ability to tailor S/Se ratio.

University researchers at CSM are developing and testing the fundamental chemistry and engineering principles. Industrial researchers at ITN are adapting PACE technology to CIGSS co-evaporation and validating PACE process for fabrication of thin film PV. In_2Se_3 films, which are used as precursor layers in high-efficiency CIGS depositions, are the first test case for the examining the advantages of PACE listed above. Gradually, this examination is being extended to the complete high-efficiency three-stage co-evaporation process.

2. Co-Delivery of Plasma-Activated Species

Work this month attacked several facets of co-delivery of plasma-activated species.

At ITN, the PACE source that was successfully tested and controlled last month was reduced in size to better fit in the CIGS co-evaporation bell jar. Although the source averages only 3" in diameter, the first version tested was approximately 16" in length, including the Se effusion pot, the quartz reactor tube, and connections. The length was reduced this month to approximately 12". The reduced dimensions allow testing of Se control, uniformity, and rate at distances from the reactor tube orifice consistent with bell jar configurations (e.g. 5"). Testing of source characteristics under these conditions is in progress. Further modifications to reduce the source length further are also underway.

At CSM, in order to gain a precise knowledge of the ratio of chalcogen to metals fluxes during co-deposition, calibration of the In flux in the PACE chamber continues. Last month a discrepancy between the apparent thicknesses of indium films evaporated at different substrate temperatures was reported. For the same nominal quartz crystal microbalance (QCM) deposition rate, films deposited on a heated substrate were significantly thicker as measured by profilometry. It was hypothesized that the difference was related to film density: i.e. the films on heated substrates were less dense, resulting in thicker films for the same mass deposition rate. Subsequent AFM imaging now supports formation of significantly different morphologies at different temperatures. Figure 1 compares films deposited at 20 °C and 200 °C. The films deposited at 200 °C have much larger grains, and the roughness is an order of magnitude larger. The films deposited at ambient temperature have much smaller grains and a smoother texture.

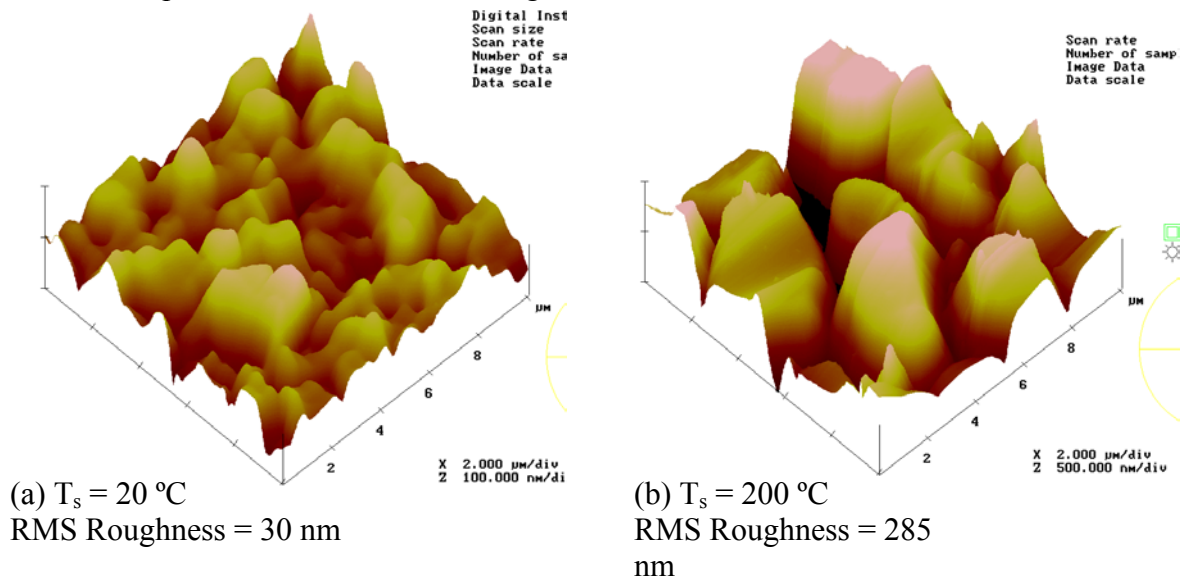


Figure 1: AFM images and RMS roughness values of films deposited at (a) room temperature and (b) 200 °C. Note that the z-scale is 5X greater in (b).

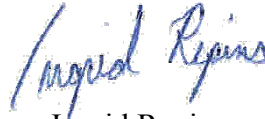
The AFM images suggest that surface mobility engendered by the higher temperature leads to the coalescence of larger grains. As these larger grains are formed they may lead to shadow effects at the microscale, leading to a columnar porous structure that would have a lower density. Thus we conclude that the QCM detector, which is always water-cooled, provides an accurate measure of the mass deposition rate, but not necessarily the linear deposition rate. We will study the impact of this effect during co-evaporation.

A novel and time-efficient method for studying the temperature dependence of plasma-assisted reactions was implemented at CSM this month. A resistively-heated and PID-controlled substrate temperature stage was installed inside the benchtop inductively coupled plasma (ICP) source. Both the heating element and the thermocouple are sheathed and grounded, and temperature is controlled during plasma operation with no observable impact on the plasma itself. Temperatures up to 600 C may be easily obtained. In previous months, copper and indium were selenized at room temperature using the benchtop ICP source. The new capability allows examination of the temperature dependence of these reactions, in an experimental setup that is relatively simple compared to CIGS co-evaporators. The new capability also allows investigation of the selenization of Cu-In-Ga films, which has proven problematic at ambient temperature.

4. Team Activities

ITN and CSM participate in CIS team activities. This month's activities relate to discussion of data, and preparation and scheduling of presentations for the November team meeting.

Best Wishes,

A handwritten signature in blue ink that reads "Ingrid Repins". The signature is fluid and cursive, with the first name "Ingrid" being more prominent than the last name "Repins".

Ingrid Repins
Principal investigator
ITN Energy Systems

Cc: Ms. Carolyn Lopez; NREL contracts and business services
Dr. Colin Wolden; CSM technical lead